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(54) Diffractive focussing means

(57) A means for focussing radiation is provided which operates by diffraction but has only a single focal length, and comprises an array 10 of discontinuous arc portions concentric about an axis, the arc portions being opaque and other portions of the focussing means being transparent. The arc portions are such that the average amplitude-transmittance t around any complete circle of radius r centred on the axis varies sinusoidally e.g. according to the equation:

$$t = \tfrac{1}{2}\left(1 + \cos\left(\frac{2\pi r^2}{R^2} + b\right)\right)$$

where R and b are constants indicating the scale of the pattern. The means may be used to focus a wide range of radiations including visible light, X-rays, and neutrons, by appropriate choice of materials and scale.

Fig.1.

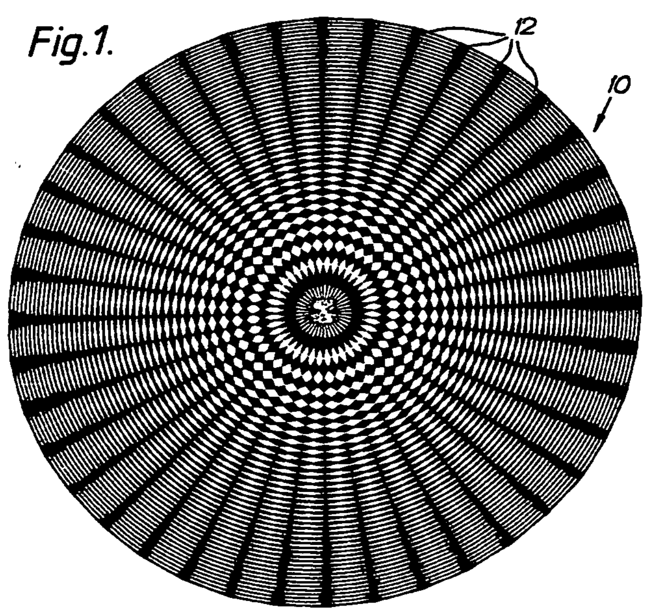

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Fig.1.

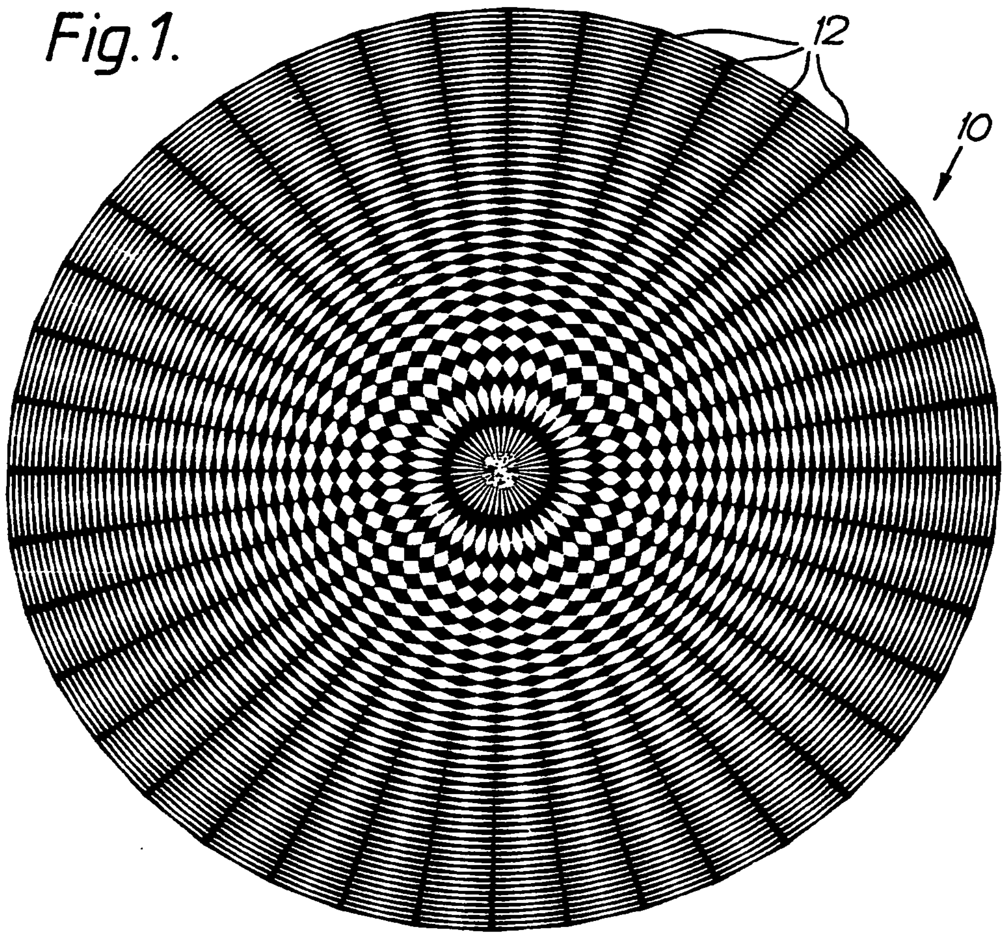
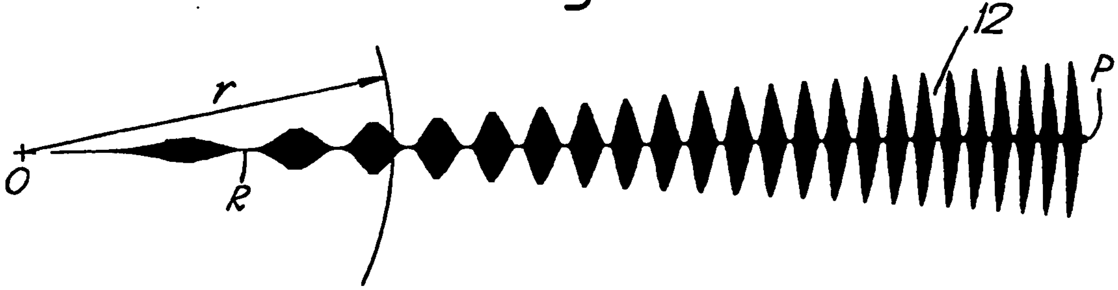


Fig.2.



Focussing Means

The invention relates to means for focussing radiation, for example visible light or X-rays.

The use of lenses to focus light has been known for centuries, and lenses have the advantage of having only a single focal length, so clear bright images can be formed. However it is difficult to find suitable materials for some types of radiation such as X-rays because the material has to be able to refract the radiation. Focussing means relying instead on diffraction are also known, for example the Fresnel zone plate consisting of concentric, alternately opaque and transparent annuli. This has the disadvantage of having several different focal lengths so the images it can produce are not as sharp as those formed by a lens.

According to the present invention there is provided a focussing means comprising an array of discontinuous arc portions concentric about an axis, the arc portions differing in their radiation transmission properties from other portions of the focussing means, the arc portions being such that the average amplitude-transmittance t around any complete circle of radius r centred on the axis varies sinusoidally with the square of the radius r.

Preferably the amplitude-transmittance t varies according to the equation:

$$t = \tfrac{1}{2}\left(1 + \cos\left(\frac{2\pi r^2}{R^2} + b\right)\right)$$

where R and b are constants for a particular focussing means. The arc portions are preferably opaque whereas the other portions are transparent to the radiation to be

focussed. The focussing means has a single focal length f given by:

$$f = \frac{R^2}{2\lambda}$$

where λ is the wavelength of the radiation. Hence the wavelength, in conjunction with the desired focal length, determine the value of the parameter R, and hence the scale of the array.

Preferably the array has rotational symmetry about the axis, and preferably at any particular radius r all the arc lengths are equal.

The focussing means may be used to focus a wide variety of different forms of radiation. For visible light the arc portions may for example be opaque portions of a photographic emulsion supported on a transparent glass plate. Alternatively they may comprise a thin metal coating on a glass plate, the remainder of the coating being removed by chemical etching. Similar methods of manufacture enable focussing means for use with infra-red or ultra-violet radiation to be made. For microwaves the arc portions might be of copper, supported on a non-conducting plate. For X-rays a nanometre-scale etching process might be used to form the arc portions in a material having a strong absorption edge at or near the wavelength to be focussed. Similarly, for focussing neutrons, a foil of gadolinium or another suitable absorber may be etched to form the arc portions, supported on a film of non-absorbing plastics material.

Although in the ideal embodiments the arc portions would be totally opaque and the other portions totally transparent, nevertheless as long as the amplitude-

transmittance varies with the radius in the specified fashion the focussing means will still operate to bring at least part of the incident radiation to a focus.

The invention will now be further described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 shows an array of arc portions for use as a focussing means; and

Figure 2 shows to a larger scale part of the array of Figure 1.

Referring to Figure 1 there is shown an array 10 or pattern forming a focussing means. The array 10 is shown in black and white, the black representing opaque portions and the white representing transparent portions. The array 10 consists of forty identical sectors 12, each of angular width 9 degrees. The array 10 hence has rotational symmetry about its centre. Along a radial line there are forty black portions between the centre and the periphery of the array 10, so the focussing means may be described as having forty zones.

Referring to Figure 2 there is shown, to a larger scale, part of a single sector 12 of the array 10. The centre of the array 10 is indicated by O, and the centre-line of the sector 12, i.e. a radial line, is indicated by O-P. Only twenty-three zones are shown in Figure 2. At a radius r is a black (opaque) arc portion bisected by the line OP and of length L given by:

$$L = \left(\frac{2\pi r}{40}\right) \times \left(\frac{1}{2}\left(1 - \cos\frac{2\pi r^2}{R^2}\right)\right)$$

The first factor is merely the arc length of the sector 12 at a radius r, while the second factor varies sinusoidally between zero and one. The parameter R determines the scale of the pattern, as it corresponds to the radius at which the arc length first returns to zero, on moving outward from the centre O.

Since the black arc portions are opaque whereas the remainder of the array 10 is transparent, the amplitude-transmittance t, averaged around a complete circle of radius r, is given by one minus the second factor in the above equation, i.e.:

$$t = \tfrac{1}{2}\left(1 + \cos \frac{2\pi r^2}{R^2}\right)$$

For use with visible light the array 10 of Figure 1 would be of overall diameter for example between 4 mm and 20 mm, for example 6.5 mm, and might comprise photographic emulsion on a glass support. If the overall diameter is 6.5 mm the parameter R would have the value 0.51 mm. If used with green light of wavelength 500 nm then it will have a focal length:

$$f = \frac{R^2}{2\lambda} = 0.26 \text{ m}$$

Such a focussing means has been found able to resolve as many as 30 to 40 line pairs per mm, when used to photograph test objects.

For use with infra-red radiation the array 10 of Figure 1 might be of overall diameter for example 50 mm, and be etched in a 30 micron thick nickel film on a silicon substrate.

It will be appreciated that the pattern used in a focussing means of the invention may differ from that described above. For example the number of sectors 12 might differ, or alternatively the number of sectors in one annular region, for example the outer half of the pattern, might be greater than that in the remainder of the pattern. It will be appreciated that the opaque arc portions within a sector 12, instead of being bisected by the radial line OP, might all have one end starting at a radial line. The sectors might not be defined between equally spaced radial lines but instead lie between equally spaced curved (part spiral) lines. There is also no necessity for all the sectors to be of the same width, and indeed the pattern of opaque arc portions may differ from sector to sector.

Furthermore, instead of the pattern being transparent at the centre O, it might be opaque at the centre, throughout the pattern the opaque and transparent portions being reversed; this corresponds to a change of phase of π radians compared to the equation for the transmittance t of the array 10. Indeed the pattern might have a radial variation of transmittance t differing from that of the array 10 by any desired phase angle between zero and 2π radians.

It will be appreciated that it may prove difficult to make the desired pattern as discussed above, particularly at large values of radius where successive zones are very narrow. To minimize this problem the pattern may be simplified for the outermost zones with little detrimental effect on the focussing properties of the array. For example the sinusoidal variations in arc length might be simplified to a triangular variation, or a stepped variation.

By way of example, a focussing means of the invention suitable for use with X-rays might be used for holographically imaging X-rays or gamma rays, so enabling the geometry of the source to be determined. Again, a focussing means of the invention suitable for use with microwaves might be used instead of a reflector for focussing satellite signals onto a detector, either for television or telecommunication reception.

Claims

1. A focussing means comprising an array of discontinuous arc portions concentric about an axis, the arc portions differing in their radiation transmission properties from other portions of the focussing means, the arc portions being such that the average amplitude-transmittance t around any complete circle of radius r centred on the axis varies sinusoidally with the square of the radius r.

2. A focussing means as claimed in Claim 1 wherein

the amplitude-transmittance t varies according to the equation:

$$t = \tfrac{1}{2}\left(1 + \cos\left(\frac{2\pi r^2}{R^2} + b\right)\right)$$

3. A focussing means as claimed in Claim 1 or Claim 2 wherein the arc portions are opaque whereas the other portions are transparent to the radiation to be focussed.

4. A focussing means as claimed in any one of the preceding Claims wherein the array has rotational symmetry about the axis.

5. A focussing means as claimed in any one of the preceding Claims wherein at any particular radius in all the arc lengths are equal.

6. A focussing means substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

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Patents Act 1977
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Relevant Technical fields

(i) UK Cl (Edition K) G2J (J33D, J33X)

(ii) Int CL (Edition 5) G02B

Databases (see over)

(i) UK Patent Office

(ii)

Search Examiner: MR C J ROSS

Date of Search: 6 MAY 1992

Documents considered relevant following a search in respect of claims 1-6

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

SF2(p)

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Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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